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Letter to the Editor re: Safety Pressure Effects in a Mechanical Demand Regulator

DEAR EDITOR:

I commend Shykoff et al.¹ for undertaking a technically complex study examining whether safety pressure (SP) in the CRU-103 oxygen regulator, when combined with a pressure-compensated expiratory valve, could contribute to unexplained physiological events in aviation.² This is an important operational and physiological question, addressed with careful laboratory work.

I read the article¹ with particular interest as a biomedical engineer developing an electronic breathing device for physiological event training in a flight simulator. My work requires replicating the breathing sensations produced by the oxygen regulator described, while delivering a freely variable oxygen fraction to the pilot mask and simulating various oxygen-equipment failure modes. Through this work, we have become very familiar with the intricate interplay between the SP oxygen regulator and the pressure-compensated expiratory valve of the MBU-series mask.

SP in the mask effectively “preloads” inhalation, making it feel assisted, while the pressure-compensated valve essential for SP operation adds to expiratory effort. As the authors note, SP assists inhalation but increases expiratory effort, while disabled SP has the opposite effect. In either case, the CRU-103 and MBU-23/P mask combination adds to a pilot’s work of breathing (WOB), whether SP is engaged or not.

A purely mechanical design has inherent limits and cannot meet all operational requirements for all pilots in all situations. SP is, in principle, an effective countermeasure against inhalation of cockpit contaminants³ and offers physiological benefits by maintaining positive airway pressure, helping to prevent alveolar collapse, and promoting alveolar recruitment,⁴ particularly under high-G conditions where acceleration atelectasis is a concern.⁵

The WOB cost arises when expiratory resistance is present constantly, even when not physiologically or operationally required. From an engineering perspective, mechanical-only control is limiting. Our next-generation breathing-system prototypes show that modern respiratory science and electronics

can provide adaptive control, maintaining contamination protection and positive end-expiratory pressure when indicated, while minimizing unnecessary expiratory load and supporting ventilation when WOB rises.

If the objective remains to preserve the current mechanical mask and oxygen regulators with spring-regulated valves, added resistance, whether inspiratory, expiratory, or both, will persist and manifest during different flight phases. This is because their rigid, fixed design lacks adaptability for all operational scenarios.

Harding’s⁶ observation remains relevant: the ideal breathing device imposes no restriction. The aviation life-support industry has yet to demonstrate, as medical ventilators in the clinical arena have, that such an advanced device can be developed and delivered to enhance pilot performance across all flight profiles while reducing WOB burden.

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IN RESPONSE:

We thank the correspondent for his interest in our work. We agree that safety pressure (SP) provides benefits to aviators. We also recognize the limitations of mechanical systems. We are not convinced, though, that adaptive control can correct for them; gas flow through tubes has its own mechanical limitations. Further, individual differences in breathing pattern coupled with physiological reflex responses risk having human- and machine-control systems “chasing” each other.

The writer’s description of the effects of SP and the pressure-compensated expiratory valve, although intuitively reasonable, misses some nuances. SP does not, in principle, assist inspiration; both mask and alveolar gas should be at SP just before inspiration begins. In practice, mechanical delay in the expiratory valve compensation system assists inspiration with SP. Because the expiratory valve cannot close instantly, mask and alveolar pressure drop slightly below regulator outlet pressure before the end of expiration. That lowered pressure slightly assists flow at the start of inspiration. Similarly, the action of the expiratory valve compensation system, not SP per se, increases the pressure needed to start expiratory flow.

Without SP there are no delays in expiratory valve cycling and also neither drops in mask pressure to assist the start of inspiratory flow nor extra valve cracking pressure to start expiration.

An adaptive control breathing system, like a mechanical regulator, can affect expiration only through action on the expiratory valve. The compensation system of the MBU-23/P expiratory valve is extremely adaptable. The pressure supplied to the mask controls the pressure to open the expiratory valve with or without SP for variable positive pressure breathing for altitude or for variable positive pressure for acceleration tolerance. The downside of the design is that valve operation cannot be instantaneous except when the supply pressure equals ambient pressure, because the compensation system relies on gas flow in narrow tubes.

A breathing system that maintained inspiratory mask pressure constant at the regulator setpoint would eliminate external inspiratory work of breathing. One that perfectly coupled expiratory valve resistance to expiratory driving pressure could match external expiratory work of breathing at any regulator output pressure to that at ambient pressure. The reality of control system limitations during rapid changes and the unpredictability of spontaneous human breathing with varied respiratory demand make those very difficult goals.

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